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Proof of Concept of The Range Ignition Probability (RIP) Tool

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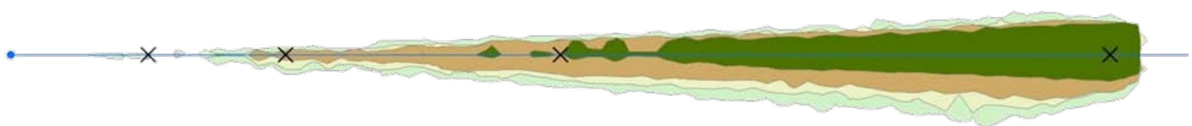
Proof of Concept of
The Range Ignition Probability Tool



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Executive Summary

The past two decades have seen increasingly large and violent wildfires and this is expected to continue into the foreseeable future. Incendiary munitions, increasing range use, a disproportionate rate of rare species presence, and fire promoting invasive species outbreaks make military installations particularly vulnerable to this trend. Assessing wildfire risk and determining best management practices requires accurate information about where fires are likely to start as ignition location can make a dramatic difference in fire outcomes. Actual ignition location data from years of training is the ideal, but in the vast majority of cases this is not available. The RIP Tool is designed to fill this information gap.

We partnered with the Army Research, Development, and Engineering Center at Picatinny Arsenal in New Jersey to modify their ballistics models for use in the RIP Tool. The RIP Tool is based on a probabilistic surface danger zone (SDZ) methodology developed by Picatinny arsenal which considers a wide variety of physical parameters as well as aimer error. It is coupled with a robust ricochet model based on laboratory and field experiments to determine ricochet probability and trajectory. This model is capable of simulating SDZ's for stationary and moving targets as well as baffled ranges.

The RIP Tool adds an additional piece of information denoting the status of the tracer compound when the round impacts the surface. We modified Picatinny's model so that rounds are not counted in the probability calculations if they impact after the tracer burns out.

We tested the RIP Tool under increasingly complex situations on a hypothetical flat range to minimize sources of error. We then applied the RIP Tool to a real-world live-fire range using engineering drawings and engineering grade elevation point data.

The RIP Tool can produce both probability contours (similar to SDZ's) as well as grid output. Probability contours are useful for quickly identifying areas at risk while grid outputs are useful when more detailed information about the distribution of ignitions is desired.

The RIP Tool provides a much more realistic estimation of where fires are likely to occur. In some instances, the standard bat wing SDZ is currently used for this purpose. Our real-world tests revealed that the RIP Tool output for 5.56 mm ammunition is roughly 4% the size of the bat wing SDZ, a drastic reduction.

We foresee outputs from a fully-functional RIP Tool being used as an input to fire risk assessments, to help determine where best to place firebreaks and fuelbreaks, and to inform the range planning process to avoid unintended ignitions in sensitive or unexpected locations.

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Introduction

The Increasing Fire Threat

Concern among fire managers has been piqued in the last decade by increasingly large and violent wildfires. Their size and intensity have increased significantly over the past two decades (NIFC 2007) (Figure 1) and this trend is expected to continue into the foreseeable future (Westerling et al. 2006). National expenditures on wildland firefighting are typically $1-2 billion per year (NICC 2006), with expected future increases congruent with increases in acres burned.

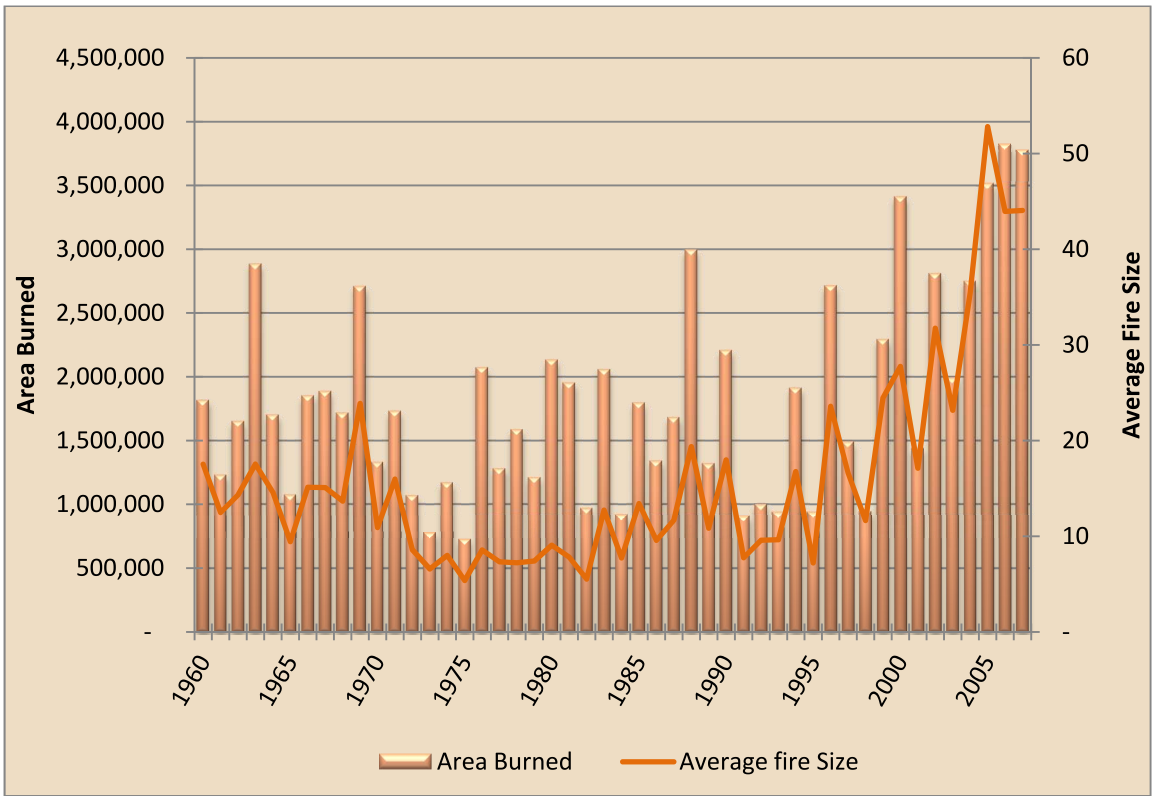

Figure 1. Area burned and average fire size per year in the U.S. 1960-2007, both in hectares. Average fire size has more than tripled in the past decade alone.

Incendiary munitions and increasing range use make military installations particularly vulnerable to this trend. Additionally, exotic plant invasions have increased fire size as well as the likelihood of ignition in some regions (Brooks et al 2004, Brooks & Pyke 2001, D'Antonio 2000), particularly in disturbed areas which are common on military training installations.

Wildfires resulting from military training pose a significant threat to training realism and land use capabilities, natural and cultural resources, infrastructure, and human/Soldier safety. Fires can burn target systems, destroy vegetation vital to cover and concealment, and threaten expensive infrastructure such as buildings or radar facilities. One of the largest threats posed by military ignited fires is to protected and rare species. Large portions of military administered lands have been protected from human development for decades, and as a result harbor a disproportionate number of rare ecosystems and species (Flather et al. 1994, Groves et al. 2000, NatureServe 2002, NatureServe 2004).

Protecting these remaining rare habitat fragments has become a major source of concern for installation commanders as well as oversight agencies and the public. The cost of managing and fighting fires, combined with rehabilitation efforts is unknown Department of Defense (DoD) wide and varies dramatically from one installation to another. However, examples from installations in Hawaii, Arizona, Wyoming, Oregon, California, and Florida suggest that it can range from several thousand to several million dollars per installation per year (personal observations and personal communications). If the Nation as a whole is any indicator, these expenditures can be expected to rise substantially in coming years.

Training and Fire-prone Weapons Systems

Despite the threat, military training requires the use of highly fire-prone weapons systems and cannot be effective without their use. Currently there are no alternatives to many of the most fire-prone munitions and the realism of training scenarios suffers substantially if they are not used.

One of the most common munitions in use today is the tracer bullet. A small amount of a brightly burning compound, usually phosphorous, is embedded in the back of the projectile. It is ignited when the round is fired and burns for a brief period of time, producing light and smoke that allows the gunner to visually follow the round to see where it is going. Tracers are used on a wide variety of direct fire weapons, and are common on small arms ranges.

One drawback to the use of tracers is that the rounds are capable of starting wildfires if they impact the ground prior to the tracer burning out. Enough tracer compound is typically used to illuminate the round to its effective range, meaning that many rounds are still in the air when the tracer burns out, thus eliminating the threat of fire. However, many rounds impact the ground prior to tracer burnout, for instance when firing downwards or at a target at close range.

Tracer munitions are known to be a primary cause of fires on military live-fire ranges. Several previous studies by Beavers (1999, 2001, 2002) showed that tracers accounted for 49%, 51%, and 48% of all fire ignitions at Makua Military Reservation, Schofield Barracks Military Reservation, and Pohakuloa Training Area respectively. By comparison, the next most common cause of ignitions, other than unknown causes or restarts of previous fires, was antitank missiles (11%), pyrotechnics (8%), and pyrotechnics (2%) at the three installations respectively.

This data shows that tracer munitions are by far the most common cause of fires on these ranges. Communication with range managers, environmental managers, Integrated Training Area Management staff and others throughout the military indicates that tracers are a primary source of ignition throughout the DoD (personal communications).

The result of so many fires is a degradation of the training environment and a risk to personnel, equipment and training facilities, protected natural and cultural resources, homes, and neighboring lands. Tracer ignited wildfires have burned threatened and endangered species, destroyed cultural resources, threatened neighboring homes, facilitated invasive species colonization and spread, and resulted in ecosystem type conversions. These fires result in a domino effect with further negative consequences in the form of greater regulatory oversight, compromised public relations, and increased expenditures on natural resource concerns such as outplanting and vegetation recovery efforts.

While a significant level of risk in military training must be accepted, the volume of tracer munitions fired on a typical range necessitates an aggressive mitigation effort, particularly on those ranges where wildfire is a significant threat. The focus of the research in this study was to develop a prediction tool, the Range Ignition Probability (RIP) Tool, to determine the spatial distribution of tracer ignition risk on a live-fire range.

Methods

Why Ignition Location Matters

The location of a specific wildfire ignition may seem to be of little relevance, particularly when large fires are being considered. However, the ultimate size and shape of a fire can be strongly influenced by its ignition location. Clearly the perimeter of a fire burning under theoretical conditions of flat terrain, constant windspeed and direction, and homogenous fuels will be determined entirely by the location of the ignition. Moving the ignition point by a given distance in a given direction will move the perimeter the same distance in the same direction.

The relationship between fire extent and ignition location becomes much more complex in the real world of fluctuating winds, variable terrain, and uneven fuel loading. Here, ignition location may have a very small or a very large effect on fire extent. Even fires that are hundreds or thousands of acres in size may be heavily impacted by ignition location (Figure 2).

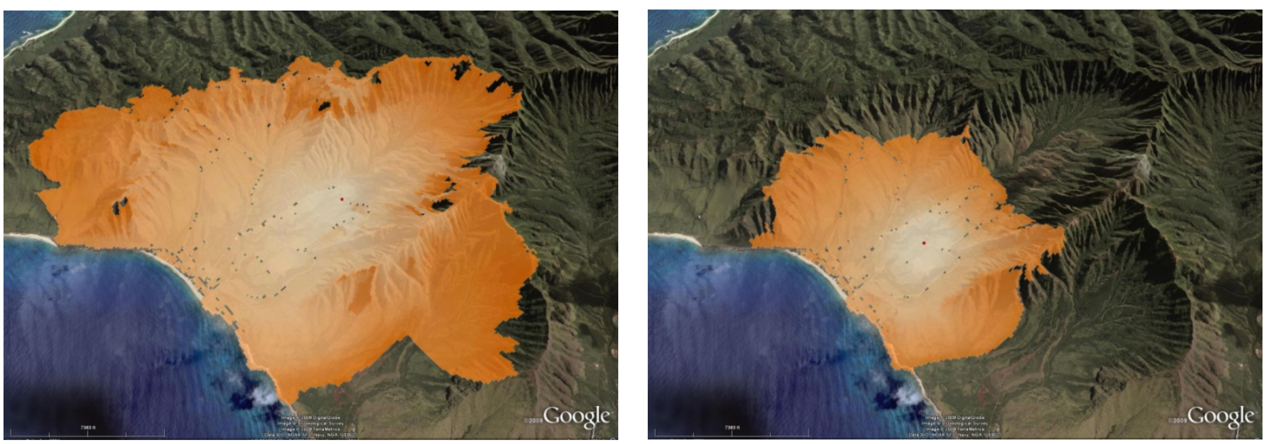

Figure 2: An example of ignition location making a major difference in fire extent. These two fires (orange area) were simulated in FARSITE, a spatial fire simulator, under identical conditions with the exception of the ignition location (red dot). The distance between the two ignition locations is 1.2 km, and both are well within the designated impact area.

Imagery courtesy of Google Earth.

Picatinny Ballistics Model

To develop our model, we relied heavily on previous research into small arms ballistics and ricochet probability developed at the Army Research, Development, Research and Engineering Center at Picatinny Arsenal in New Jersey. In the 1990's, they developed a probabilistic model to ascertain projectile dispersion on live-fire ranges (Hoxha & Vazquez 1995, Vazquez & Hoxha 1995). The purpose of their model was to develop more accurate surface danger zones (SDZs) that more fully account for

factors affecting the risk associated with live-fire ranges. The SDZs produced by this tool are termed 'probabilistic SDZs'.

Probabilistic Models

A probabilistic model works by assigning a probability to all of the possible outcomes of an event. Typically this is applied using historic data, for instance investors often use the past history of a fund to determine its probability of being profitable in the future. In the case of SDZs, the intention is to determine the probability before a round is ever fired on the range, so a different approach is required.

The Picatinny Probabilistic SDZ Model

Since bullets in flight are governed by well understood physics, their trajectories can be calculated. Typical errors made by Soldiers firing weapons can be measured, and ricochet characteristics can be experimentally determined. It is therefore possible to simulate with great accuracy the trajectory, and the possible ricochet trajectories, of individual rounds. By simulating numerous events, it is then possible to essentially create a history from which one can determine probabilities of impact at any given location. In the case of the ballistics model, the event of interest is a round being fired from the firing line towards a particular target and the outcome of interest is generally a contour defining the 1:1,000,000 probability of a round impact.

The Picatinny probabilistic SDZ Model (hereafter 'ballistics model') simulates many rounds being fired at each target on the range and accounts for a wide variety of factors including shooter position, meteorological conditions, projectile physical properties, terrain, and aimer error. Each round simulated is assigned an aiming error based on a probabilistic curve. The ballistics model then calculates where the round will impact the ground. At this point it calculates the angle of impact, based on the trajectory of the round and the angle and aspect of the surface it is impacting, and determines whether or not a ricochet is possible. If a ricochet is possible, it calculates the probability of a ricochet in all of the possible directions. It then calculates the trajectory and velocity of each of the resultant ricochets and where they will impact, then repeats the process until all of the resultant ricochets come to rest.

The range is split into a grid and the ballistics model tallies how many rounds come to rest in each grid cell (usually 10 m on a side). Because each round fired can result in many possible ricochets and each of the possible ricochets is computed via a probability (a fraction of a round), the tally is usually counting 'fractions of a round'. By using these calculations, it is possible to assign a number to the probability of a round landing anywhere on the range.

Generally, the probabilities in these cells are then used to create probability contours defining the outer edge of, for instance, the 1:1,000,000 chance of a round impact. The cell probabilities, however, can be used in a number of ways as is discussed later.

To ensure there are enough rounds to 'fill' all of the grid cells and that the results are statistically sound requires the simulation of many rounds. In a typical scenario that includes one firing point and one target, it is necessary to simulate several thousand rounds fired, which then balloon into several million potential ricochet trajectories since each round can potentially ricochet in a wide variety of directions. When simulating a range with many targets, hundreds of millions of trajectories are calculated making the simulation computationally intensive.

Aimer Error

A major factor in the dispersion of rounds on a range is the accuracy with which the shooter fires at the target. Every target on a range has one correct aiming solution - the elevation and azimuth of the weapon - that will result in the round hitting the center of the target. The ballistics model computes an aiming solution through an iterative process for each firing point/target combination. This solution ensures that a round fired with these parameters under the given meteorological conditions will hit the center of the target.

The degree to which the shooter deviates from the aiming solution is termed 'aimer error'. Aimer error in the ballistics model is based on empirical results from background research conducted by Picatinny Arsenal (Bascone, unpublished). A normal curve defines the aimer error probabilities. The curve is defined with the mean being the correct aiming solution and a standard deviation based on real-world measurements of aimer error when firing at a target at a specified distance. Aimer error changes with distance to the target as well as with weapon type, ammunition, and level of stress (Bascone, unpublished). Two curves are used, one for the azimuth and one for the elevation, each with its own mean and standard deviation. The curves are split into 'bins'. The probability of the model picking a specific azimuthal or elevational aiming error for an individual simulated round is determined by the average probability of the bin (Figure 3).

The number of bins used depends on the variability in the terrain and how smooth a final probability contour is desired. More bins are necessary in rougher terrain and will produce a smoother final probability contour. Generally it is the elevational aimer error that requires more bins, but situations where there are dramatic variations in terrain with changes in azimuth can also require a greater number of bins in the azimuthal aimer error.

The above description of the ballistics model is simplified considerably. A great deal of effort was expended in the model's development, including a significant amount of empirical data collection. We will not discuss the ballistics model in further detail here, but reports detailing its development (Hoxha & Vazquez 1995, Vazquez & Hoxha 1995) can be obtained from Picatinny Arsenal.

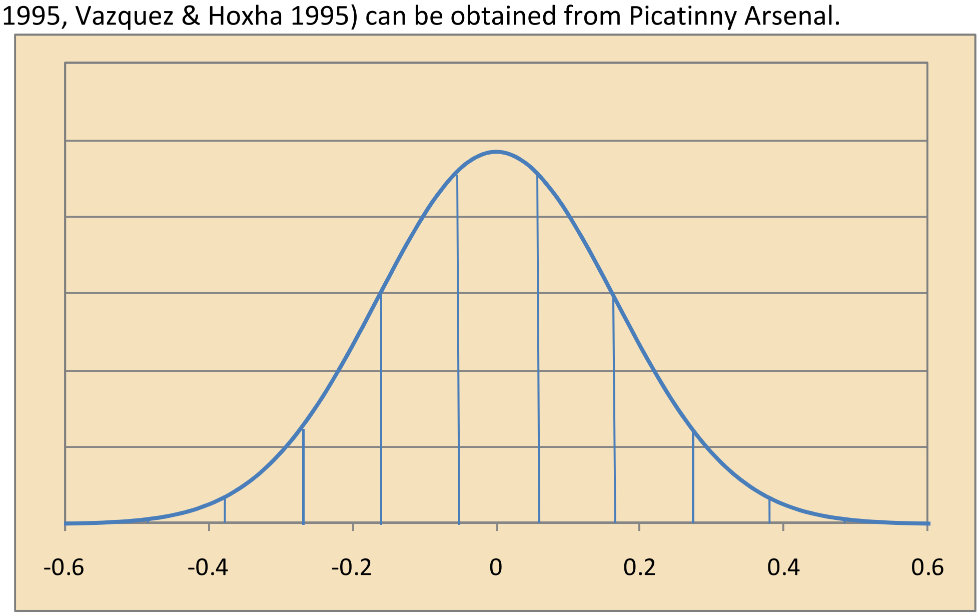

Figure 3. An example normal distribution curve with a mean of zero and a standard deviation of 0.165 degrees divided into 11 bins. The ballistics model randomly assigns aimer error weighted by the average bin probability (e.g. the area under the curve).

Creation of the Range Ignition Probability Tool

The ballistics model forms the basis of the Range Ignition Probability (RIP) Tool and was modified to suit the needs of determining fire ignition probability from tracers. The primary difference between the RIP Tool and the ballistics model is that the RIP Tool requires an additional parameter denoting the status of the tracer compound (burning or not burning) when the round impacts the surface.

We determined the burning time of tracers from tests carried out by Picatinny Arsenal. This data was collected when testing the rounds for performance in real-world conditions. The actual time the tracer burned when fired was tested, as opposed to more recent manufacturer tests that are regularly carried out that only test whether the round meets the minimum specifications in a pass/fail methodology.

To account for tracer burnout, we collaborated with Picatinny Arsenal to modify the ballistics model so that rounds were not counted in the tally of impacts if they impacted after the tracer would burn out, based on the amount of time since the round was fired. Additional modifications were made to the ballistics model to increase its calculation speed and streamline its processes. In essence, these modifications created the RIP Tool.

The model does allow for ignitions where tracer rounds ricochet if the tracer compound is still burning. The probability of an ignition at each ricochet point is equivalent to the probability that the round does not ricochet, a value calculated by the ricochet model. Thus, very steep angle impacts result in a higher ignition probability than impacts at a shallower angle.

Assumptions

As is true of any model, a number of assumptions are required to run the RIP Tool. Several variables play a part in the flight of the projectile through the air - air density, wind speed, and wind direction - and the accuracy of the shot - namely shooter position. We used a standard set of assumptions for all simulations in this study.

Air density is affected by temperature and altitude, with higher temperatures and altitudes resulting in lower air densities and greater projectile flight distance. We assumed an air temperature of 29.4° C (85° F) and an altitude of 305 m (1000 ft).

Wind speed and direction influence the trajectory of a projectile in flight. We assumed a wind speed of 10 m/s (22.37 mph) in each of the x and y vectors, which is equivalent to 14.14 m/s (31.63 mph) from behind and to the right of the shooter at a 45° angle. This results in a situation where the round is pushed as far and as off target as is reasonable to assume.

Shooter position and single shot versus burst mode affect the distribution of the aimer error budget. Less stable positions, such as standing, result in greater aimer error. Burst mode results in greater aimer error than single shot mode. We assumed a prone shooter using a bipod (a very stable position) firing in burst mode.

These assumptions are merely for the purposes of carrying out the demonstration of the RIP Tool. In actual application an assessment of each variable would be made to accurately account for the conditions at the range. Consideration would need to be given to the altitude, typical shooter positions, and weather conditions. In most cases it would be advisable to assume a worst case shooter position (standing in burst mode) to provide a more conservative estimate of round dispersal. Weather

conditions could be determined using percentile weather (90^{th} or 97^{th} percentiles), or worst case conditions could be constructed based on weather records.

Flat Terrain Simulations

For the purpose of this proof of concept and for all of the simulations we ran, we simulated the use of the 5.56 mm M856 tracer round fired from the M16. This is a commonly used small-arms munition on many live-fire ranges. In addition, the ballistics model is currently capable of simulating the 5.56 M196 tracer, 7.62 mm M62 tracer as well as ball ammunition for the 5.56 mm M193, 5.56 mm M855, 7.62 mm M80, 9 mm M882, and the .50-caliber M2 and M33. With slight modifications the RIP Tool could be utilized to simulate tracer rounds for any of these munitions.

For simplicity, and to ease the identification of errors, we first tested the RIP Tool on a hypothetical firing range with one firing lane, one target at 400 m, and a flat surface. We assumed the center of the target and the muzzle to be one meter above the surface. We also assumed worst case wind conditions of 14.1 m/s (10 m/s in each of the x and y vectors or approximately 31 mph) at a 45 degree angle from behind and to the left of the line of sight. We used 21 bins for both the azimuthal and elevational aimer errors and produced a 1:1,000,000 probability contour.

Because the majority of rounds fired in the RIP Tool do not come to rest while the tracer is still burning, additional rounds must be fired in order to fill the output grids sufficiently to be statistically relevant. For this reason, many more rounds need to be fired in the RIP Tool than are necessary in the ballistics model. In our simulations, this resulted in 3 to 8 million trajectories being computed for a single target. To ease the computing burden, we modified the program to stop computing trajectories for rounds whose tracers have burned out.

Once we were satisfied with the results we were seeing with a single target, we added complexity to the test by simulating a typical firing lane with targets at 100, 200, 400, and 800 m. This test was run with the same assumptions as those for the single target simulation. In order to produce a single probability contour for all the targets in the firing lane, we merged the results, with the final contour representing the most wide-ranging results for all targets.

Moving Targets

The ballistics model and the RIP Tool are both capable of modeling moving targets. Moving targets are addressed by simulating multiple stationary targets along the moving target's track. The reverse can be simulated as well, a 'run and gun' scenario where the shooter is moving and the target is fixed, or even where both are moving.

We simulated a single moving target on flat terrain. The target track was oriented at a 45 degree angle to the gun target line. This is to simulate the more difficult orientation, as opposed to the perpendicular orientation which does not require a significant adjustment in the range of the target as it moves along the track. The center of the track was assumed to be 250 m from the firing point and the track was 15 m long. We simulated one target on each end of the track and three evenly spaced along the track.

Real-World Simulations

Finally, we tested the RIP Tool on a real-world live-fire range in Hawaii. The range we selected for our test is a multi-purpose range at Schofield Barracks Military Reservation on Oahu (Figure 4). The range has 6 firing lanes, each with 16 to 17 targets. Again, the simulations represented 5.56 mm M856 tracer ammunition.

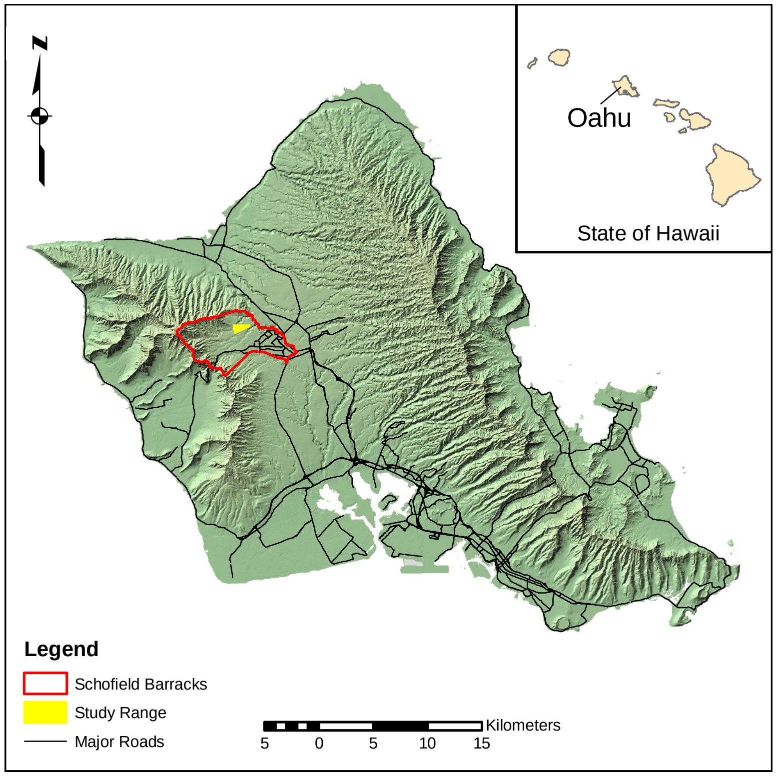

Figure 4. Location of Schofield Barracks and the range simulated.

We obtained engineering drawings of the range from the U.S. Army Garrison, HI in Microstation format and converted these to ArcGIS format. We also obtained engineering grade elevation point data covering the range from the Garrison. The point data is dense enough to produce a digital elevation model (DEM), and we used standard GIS techniques to produce a 10 m resolution DEM. We did not use U.S. Geological Survey elevation data because the range had been realigned, including some grading, since the USGS data was produced.

Input data for the location of each target and each firing point was acquired from the Microstation data. For the purposes of this proof of concept, we assumed the center of each target and the rifle muzzle at each firing point to be two meters above the surface. The targets are protected behind a berm and when up are elevated, and the firing points are elevated firing positions meaning both are elevated roughly 2 m (Figure 5).

Figure 5. An elevated firing position (left) and a target (right) on the MF-2 range. Note that the range was recently realigned resulting in a lack of vegetation.

During actual use of the RIP Tool, it would be necessary to have very accurate data. Depending on the data available, this may require traveling to the range and physically measuring the location and elevation of each target and firing point. It may also necessitate obtaining a DEM with

greater accuracy and resolution to ensure that all of the small hills and dips are accounted for when ricochet probabilities and angles are being computed.

In the more complex terrain of the real-world simulations, we increased the number of elevational aimer bins to 101 to ensure an even dispersion over the terrain, but left the azimuthal bins at 21. We merged our results in the same fashion as the flat terrain simulations to produce a single 1:1,000,000 probability contour for the entire range. We then simplified the resulting contour to eliminate pockets where the terrain precluded rounds from landing but which were surrounded by the 1:1,000,000 contour. We also produced a standard bat wing SDZ for this range based on the 5.56 mm M856 round for comparison purposes.

Finally, we used the raw probability files to produce ignition probability surfaces. We converted the ascii probability files, the raw output of the RIP Tool from which the contours are created, into Arc/Info GRID rasters. We then overlaid all of the grids and added the probabilities in each cell. This produces a cumulative probability for each 10 m x 10 m cell on the range. This type of output is more useful for some applications where more detailed information about ignition probability is required.

Results and Discussion

Single Target, Flat Terrain Simulation

Figure 6 depicts the results from the simple flat terrain simulation with a single target at 400 m. Despite millions of trajectories calculated, the contour still appears rough. It is not perfectly smooth for two reasons. First, the contour is developed from a grid output. The contour hitches from one grid cell to the next because grids are square, though some smoothing of the contour is part of the process. Second, the output grids are not evenly filled, even when firing thousands of simulated rounds with millions of ricochet trajectories. It is possible to produce a contour with a smoother outline by firing more rounds. However, the computational time required is considerable and the result, while aesthetically more pleasing, does not change the outcome meaningfully.

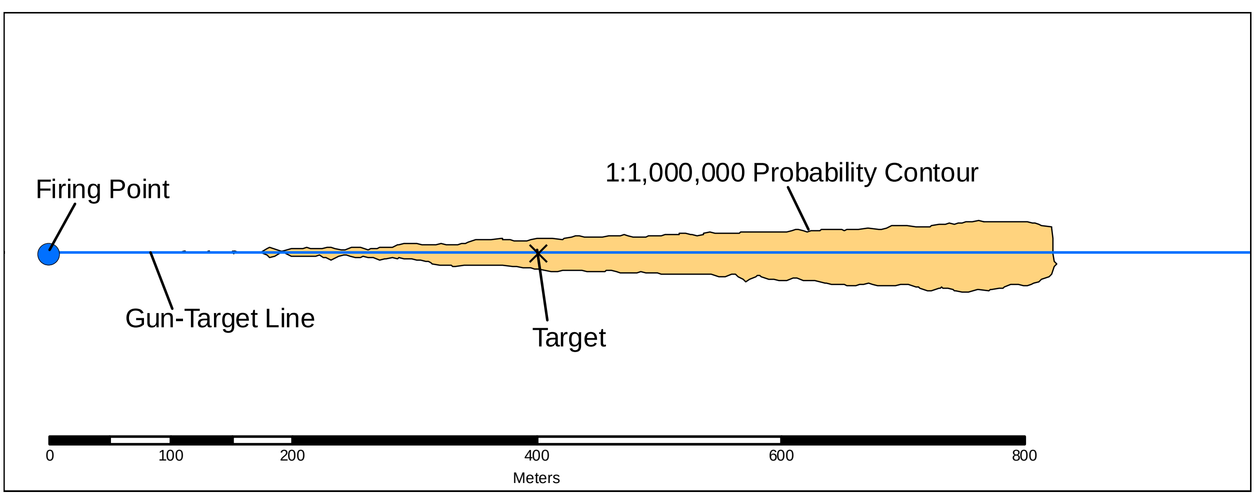

Figure 6. Sample results for a hypothetical target at 400 m on flat terrain.

The area at risk of a round coming to rest while the tracer is still burning is quite small because the tracer burnout, in effect, shortens the range of the simulated round. For comparison, Figure 7 shows

the 1:1,000,000 probability contours for tracers computed by the RIP Tool compared to that for all rounds computed by the ballistics model. The area covered by the tracer contour is less than 4% of the area covered by the contour representing all rounds.

Both the tracer contour and the contour for all rounds are slightly skewed to the right of the line of sight of the shooter due to the rotation of the round caused by rifling of the weapon. This rotation causes rounds to trend slightly to the right through the air, and to trend to the right when they ricochet off a surface. Though the high wind speed in these simulations does have some effect, it is insufficient to be noticeable at the scale of these figures. For example, a round fired at an 800 m target is shifted by less than one meter over the course of its 1000+ m flight due to the wind.

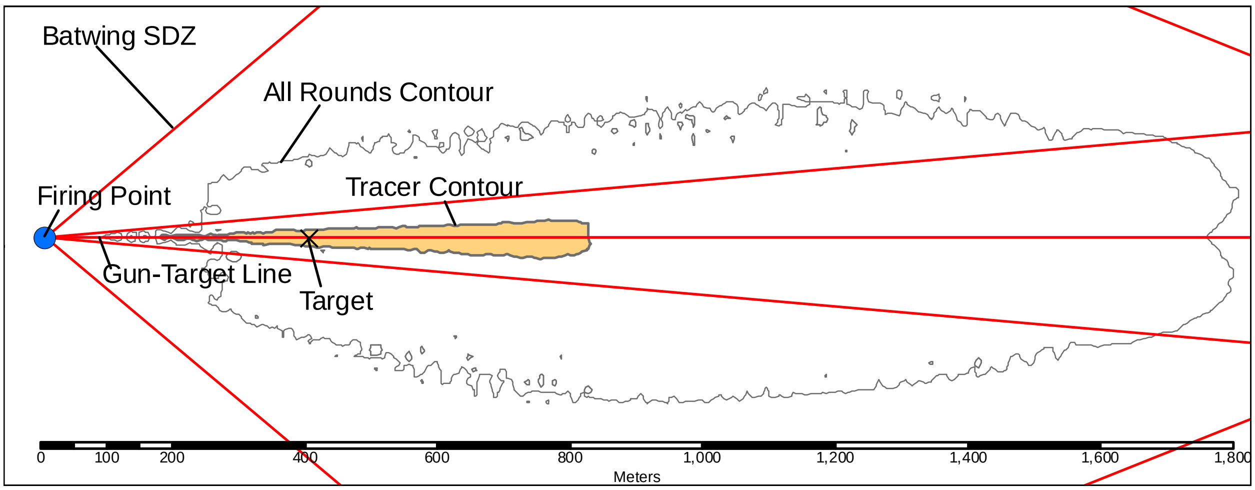

Figure 7. Sample results comparing the output from the RIP Tool to the output from the ballistics model and the bat wing SDZ on flat terrain with a single target at 400 m. Because the tracer burnout time limits how far a round may travel, the RIP Tool results are much more compact. Only part of the bat wing SDZ is shown.

Single Firing Lane, Flat Earth Simulation

The results from the simulation of a single firing lane with four targets on flat terrain are displayed in Figure 8. Note that few rounds impact before roughly 150 m. This is because the aimer error cone does not intersect the surface until some distance from the muzzle is reached (Figure 9). The distance depends on the height of the muzzle and the aimer error which is dependent upon the distance to the target as well as the weapon being fired. In the case of the data in Figure 8, the broadest aimer error is for the 100 m target. This is evident in the size of the 1:1,000,000 probability contour for the 100 m target as well. Nonetheless, most of the rounds fired at close range targets impact beyond the target.

When we combine the contours for each of the four targets to produce a single contour for the firing line (Figure 10), the results look very similar to those in Figure 6 where we simulated a single target at 400 m. This is because the aiming solution and associated aimer error for a target at 400 m produces quite a large contour. In fact, the closer a target is to the firing point, the larger the probability contour, as can be seen in Figure 8. This is due to a number of factors that influence aimer error, primarily that a target at close range appears larger to the shooter and requires less precise aim than a target of equal size that is far away.

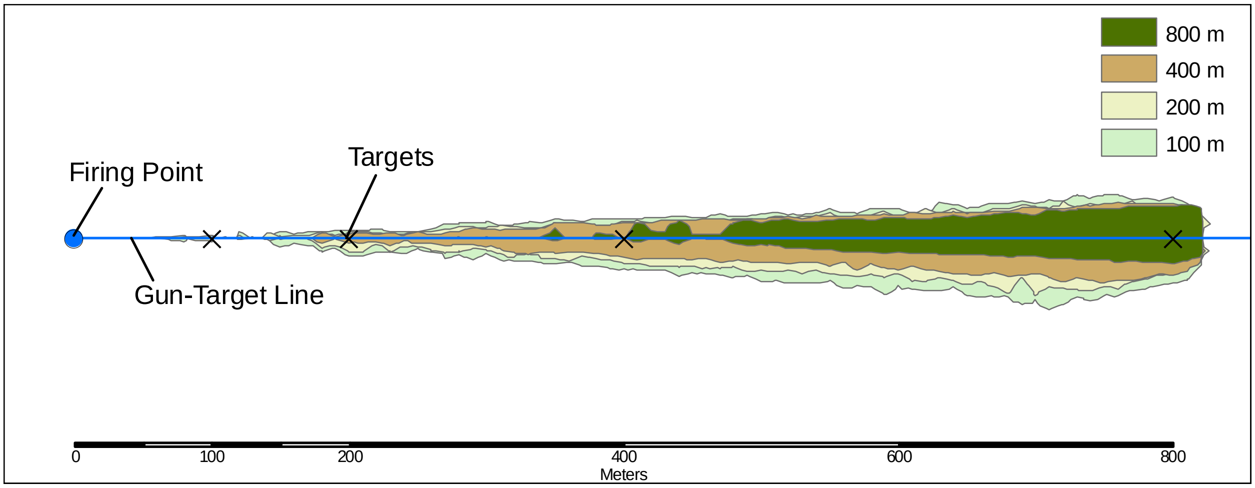

Figure 8. Sample results for a hypothetical firing lane with four targets, one each at 100, 200, 400, and 800 m with each target's 1:1,000,000 contour shown. Closer targets generally have larger contours due primarily to greater aimer error at close range.

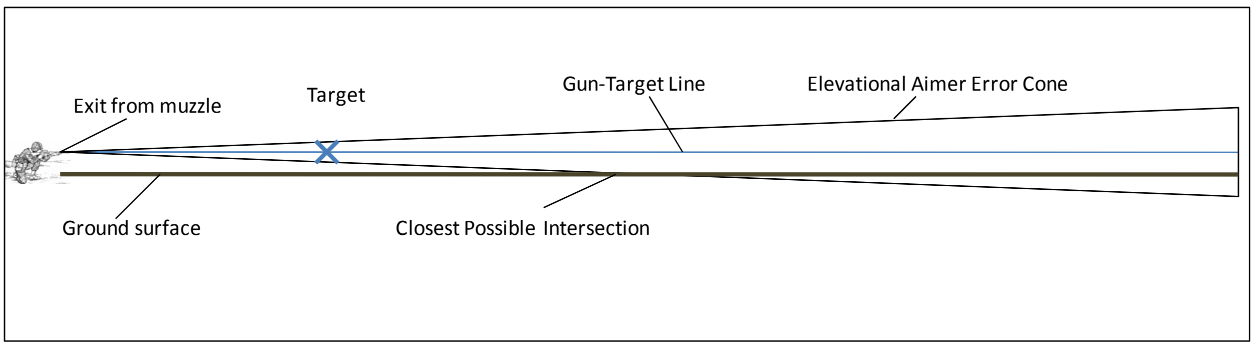

Figure 9. Side-view schematic illustrating why rounds are unlikely to hit the ground close to the muzzle.

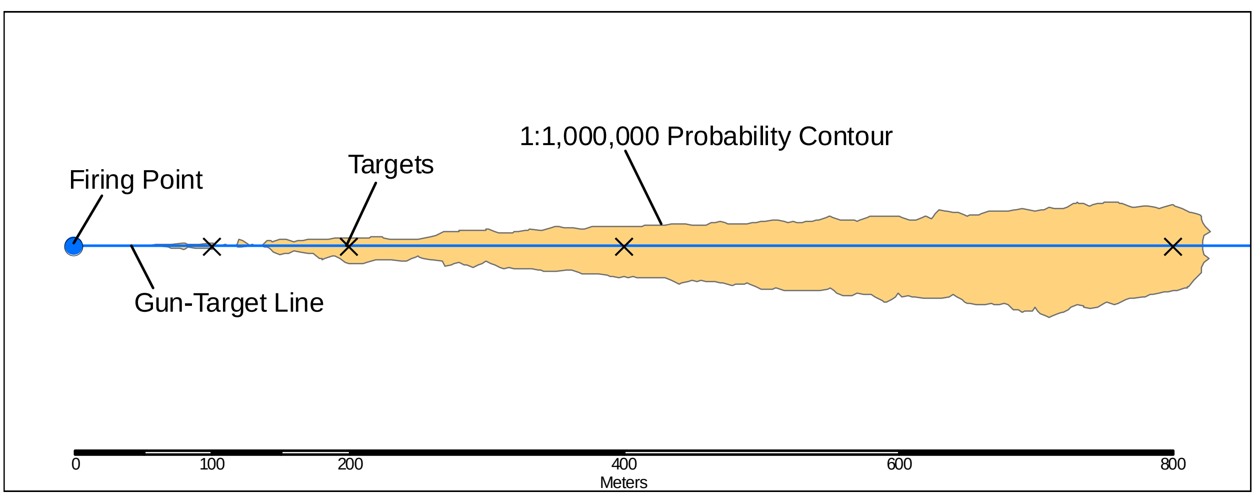

Figure 10. Sample results for a hypothetical firing lane with four targets, one each at 100, 200, 400, and 800 m on flat terrain. The 1:1,000,000 contour for each target is combined to produce a single 1:1,000,000 contour for the entire firing lane.

Moving Target, Flat Earth Simulation

The results for the moving target on flat earth simulation are shown in Figure 11 with a 1:1,000,000 probability contour. The resultant contour is slightly wider then either the single target or the single firing lane simulations.

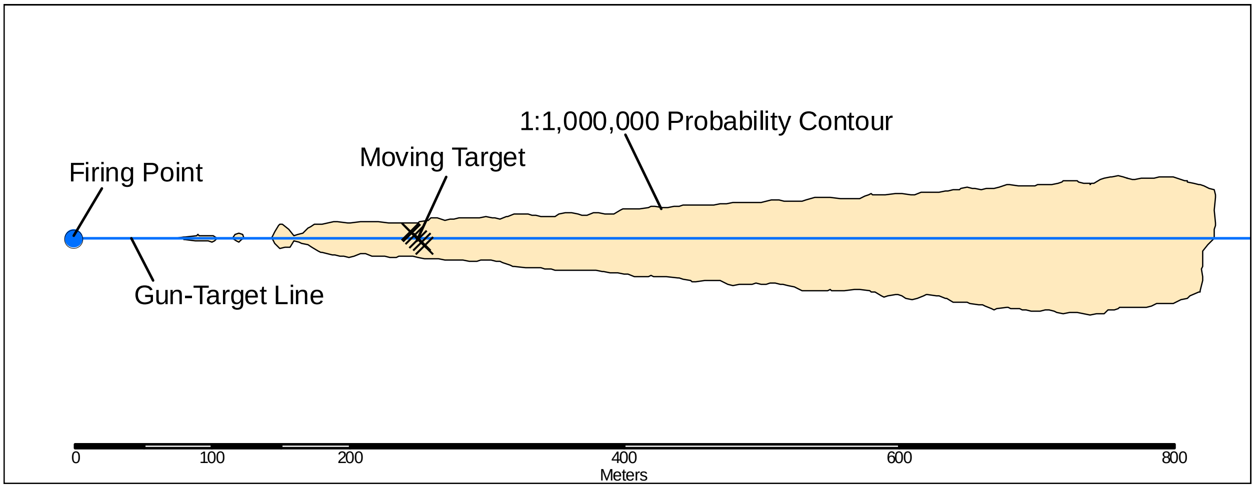

Figure 11. Sample results for a hypothetical firing lane with a single moving target centered at 250 m on flat terrain. The moving target track is 15 m long and is oriented at 45° to the gun-target line, which in this case is only shown for a target at the center of the moving target track. Moving targets are addressed by simulating multiple stationary targets(X's above) along the moving target's track.

Real World Simulation

Our results from the real-world simulation are much more complex than any of the flat terrain simulations. Figure 12 displays the 1:1,000,000 contour for the range. The small dips and hills on the range shield large areas from being impacted. A significant portion of the area within the target complex is not at risk of tracer ignition.

The results show that large portions of a range can be precluded from a round impact by even very slight variations in terrain. Because the rounds are traveling nearly parallel to the surface, they fly over the top of small dips or are blocked from the far side of small lumps in the terrain.

Two of the targets on the range did not have an aiming solution. Though the targets can be hit on the real range, slight inaccuracies in our DEM make these two targets impossible to hit in simulations. This highlights the importance of very accurate data when running the RIP Tool and why relying on installation developed data may not always be possible. It is our belief that the elevation data we received was inaccurately labeled as post-construction, when in fact it was data from before the range was re-graded. A site visit to the range in late 2008 confirmed this suspicion.

This inaccuracy resulted in the targets being behind small hills in our DEM that do not exist anymore on the actual range. Better input data would very likely clear up this issue, though we did not attempt to rectify the situation for this proof of concept. In actual use, LIDAR or RADAR elevation data would be most suitable to the RIP Tool due to its exceptional accuracy and precision compared to any other method of determining elevation. However, cost factors may preclude this as an option and in those cases engineering grade data and/or point data from a site visit would usually suffice.

Comparison to the Standard Bat Wing SDZ

The bat wing SDZ is a commonly utilized method to represent the area of 1:1,000,000 probability for round impacts on a range. It is sometimes also used to define the area at risk of fire ignition. When the 1:1,000,000 contour produced by the RIP Tool is overlaid on the bat wing SDZ for the MF-2 range, it is immediately evident that the RIP Tool output is drastically smaller than the standard bat wing SDZ for this range and ammunition (Figure 12). This is partially due to the reduction in flight distance since the RIP Tool only represents those rounds that hit the ground while the tracer is still burning. It also reflects the greater accuracy with which the Picatinny ballistics model predicts round dispersion and ricochets on a range as was demonstrated in Figure 7.

Grid Outputs

The grid outputs depicted in Figure 13 display the raw results of the simulation. Each grid cell represents the cumulative probability of rounds from any of the 103 targets on the range landing in that cell while the tracer is still burning. This type of output provides much more detailed information than the contour output.

Users will notice there are slight disparities between the grid output and the contour output due to differences in how they are calculated. Rather than connecting each of the grid cells with a value of 0.000001 and interpolating between cells when necessary, the contour program counts up the grid cell values in order from greatest value to lowest until it reaches a value of one (a total of 100% probability). This is mathematically more accurate but spatially results in mild differences between the contour and the 1:1,000,000 grids. This difference is small and not considered to be significant in practical terms, particularly because the areas where it is most pronounced are those locations where the ignition probability is lowest.

Grid data will not usually be useful for an individual range, but when a number of ranges or an entire impact area is considered, these data much more accurately define the most likely ignition locations when compared to contour output. In the case of Schofield Barracks, if we were to simulate all of the ranges and indirect fire target areas and combine the results, it would be possible to say with some confidence where fires are most likely to occur throughout the installation and, conversely, where they are not likely.

Information like this can help in fire prevention and fire suppression activities. Most notably, this information can be used to ensure that the probability of a munitions ignited fire starting in undesirable areas is very low, or possibly even zero. Firebreaks, rare species locations, or other data of interest can be overlaid on the grid output to determine whether fires may start in the vicinity of important resources or primary fire corridors.

Grid data can also be utilized to identify the most common ignition locations. This information can be used to plan firefighting tactics and strategies and when simulating wildfire risk. Common methods of calculating wildfire risk include simulating many fires and assessing where they tend to burn. A major factor in determining the overall wildfire risk is the location of the ignitions from which the simulations are started. The grid outputs from the RIP Tool are an excellent way to provide these ignition locations. Each simulated fire can be started at a point randomly determined, but weighted by the ignition probability grid. Thus, simulated fires are more likely to start where the ignition grid shows a high probability of ignition. The only better data would be actual ignition location data from years of training

on the range – data that is rarely available and is unavailable for ranges that are being planned or realigned.

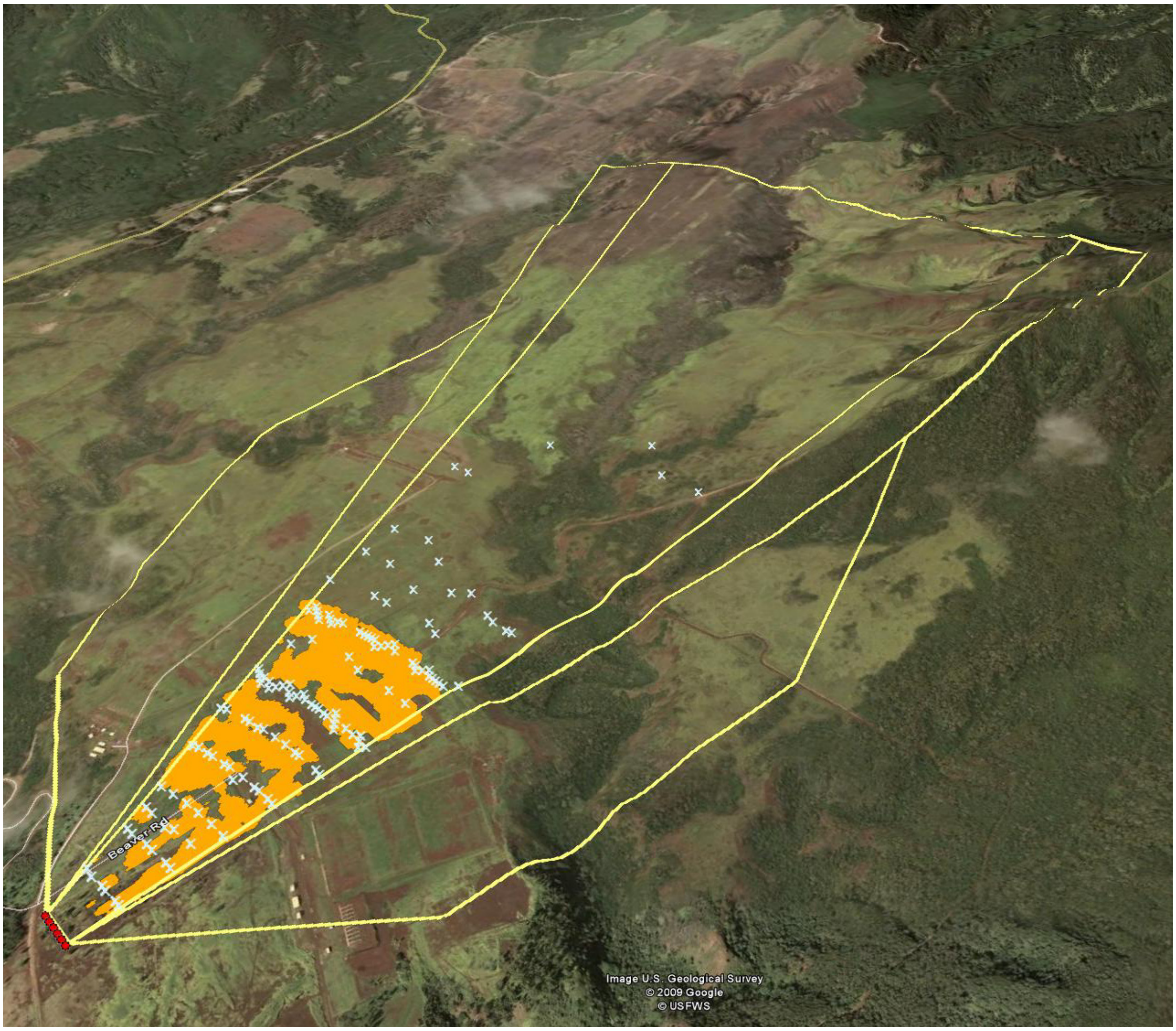

Figure 12. Real-world test of the prototype RIP Tool on the MF-2 Range at Schofield Barracks, Hawaii for 5.56 mm M856 tracer ammunition. The area affected by potential ignitions according to the RIP Tool (orange) is 3.6% the size of the bat wing SDZ (yellow line). Red points are firing points and X's are targets.

Imagery courtesy of Google Earth.

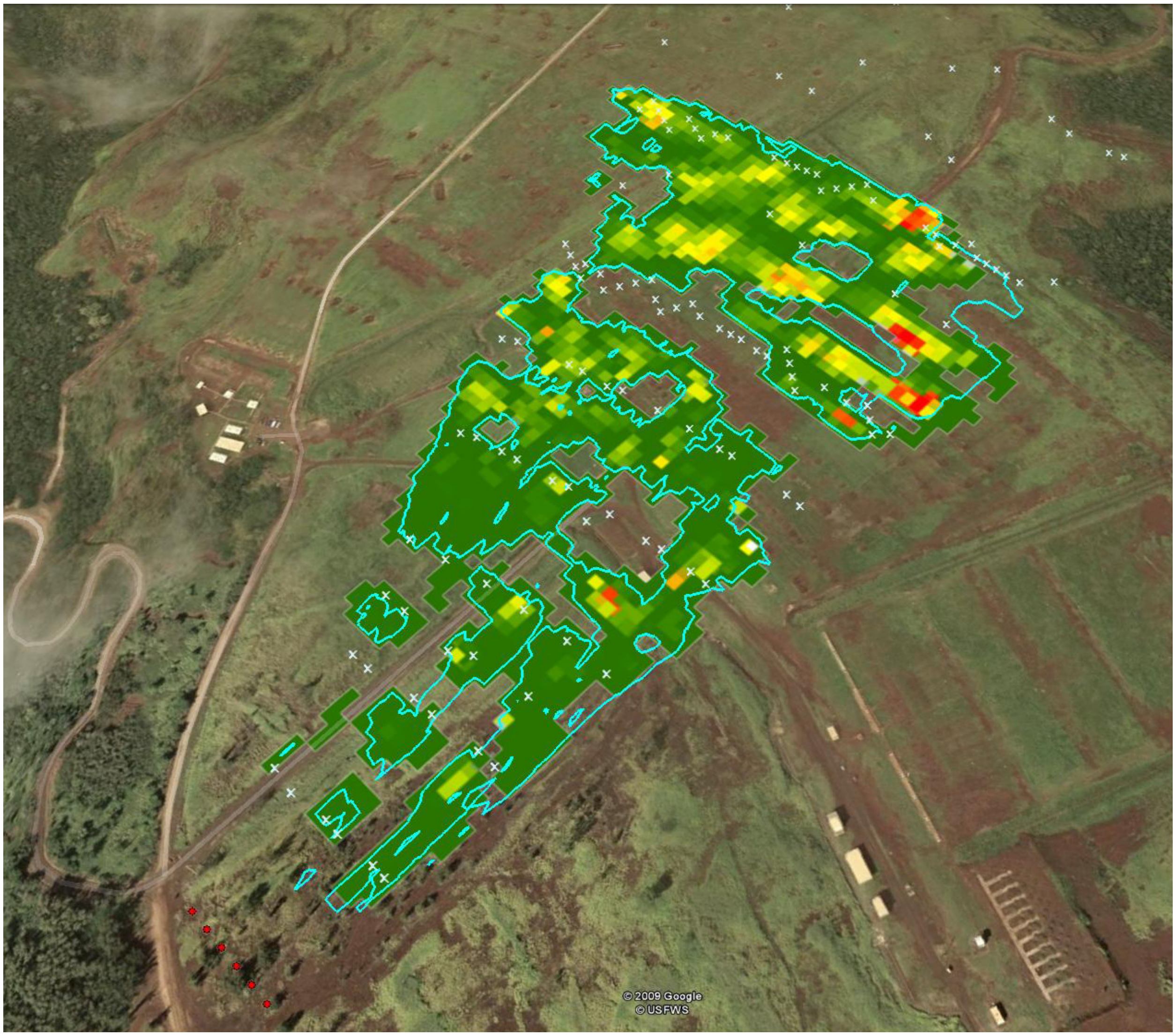

Figure 13. Comparison of the grid outputs to contour outputs. Red dots are firing points, X's are targets. The light blue contour is the 1:1,000,000 contour and the grid data ranges from low probability of ignition (green) to high probability (red). There are some disparities between the grid and the contour due to slight differences in the way they are calculated. Grid data provides a great deal more information than contours alone. Though probably not useful on a single range, when multiple ranges or an entire impact area are considered, this more precise information can be critical for fire management.

Imagery courtesy of Google Earth.

Simplification of Results

At first glance, the results from the MF-2 range suggest that it may be possible to develop rules of thumb for ranges on relatively flat terrain like this one. Generally speaking, for the 5.56 mm M856 tracer round, the area at risk from ignition starts roughly 50 m from the firing line and extends to the tracer burnout distance of about 900 m. The latitudinal area at risk runs from roughly one range limit to the other.

However, more simulations on other ranges need to be run before any conclusions about a rule of thumb like this can be made. Also, other munitions, particularly larger caliber munitions like the .50 caliber, will likely require a different rule of thumb, and all of these would only be valid on relatively flat ranges. More complex terrain and other weapons systems, such as artillery or mortars, will also likely produce more complex results. We expect to answer these questions in a follow up to this study designed to develop a fully functional RIP Tool, but we expect that the answers will not be conducive to creating simple rules of thumb.

Future Directions

The RIP Tool developed for this study is a proof of concept. It is limited to the 5.56 mm M856 tracer round. Our results clearly show the feasibility of developing a fully functional RIP Tool that could simulate many more types of munitions including indirect fire weapons. Ballistics data already exists to simulate the 7.62 mm M62 tracer round and the 5.56 mm M196 tracer, both common munitions. Ballistics data on .50 caliber M2 and M33 ball ammunition is also available. Since the differences in ballistics between tracer and ball ammunition of the same type and caliber are very small, ricochet data from the .50 caliber ball munition could be applied to .50 caliber tracers, pending some assessment of the accuracy of using this data in this manner. Additional ballistics testing could be undertaken to develop ricochet data for the .50 caliber tracer if that is deemed necessary.

Additionally, in conversations with personnel at Picatinny Arsenal we have come to the conclusion that it would very likely be possible to apply the same principles we have illustrated here to indirect fire weapons such as artillery and mortars as well as tanks and rockets. Such an advance in the capabilities of both the ballistics model and the RIP Tool would require collaboration with Picatinny Arsenal and preliminary talks have been promising. Development of this capability would greatly enhance the usefulness of the RIP Tool since entire ranges could be simulated. This would vastly increase the inclusiveness of the model and minimize the number of weapons systems unaccounted for when assessing ignition probabilities on a range.

Other Considerations

It is possible to create contours for six different probability levels. We used the 1:1,000,000 contour because that is the probability commonly accepted for safety issues and it is what is represented by the current SDZ methodology. However, there may be situations where a greater or lesser degree of certainty is required. Slight modifications in the form of the number of simulated rounds fired, and the number of bins for the aimer error curves would be required. The result of increasing the certainty increases the size of the contours, and decreasing the certainty decreases the size of the contours, though the degree of the size change would depend on a number of variables. The contour values currently available are 1×10^{-3}, 1×10^{-4}, 1×10^{-5}, 1×10^{-6}, 1×10^{-7}, and 1×10^{-10}. The RIP Tool grid output is limited to probabilities of greater than 5×10^{-13} (1 chance in 2 trillion) due to rounding constraints.

Clearly, a tool like this cannot account for random events such as an accidentally discharged weapon or the use of a weapon or ammunition that is not authorized for the range. Such events are stochastic and by their very nature unpredictable. Current safety methodologies recognize that these situations cannot be predicted and the RIP Tool follows in this line of thinking.

The Picatinny Arsenal ballistics model has been used to refine SDZs on selected ranges throughout the U.S. but is not available to installations for in-house use. Only a few personnel at Picatinny Arsenal are currently authorized to use the ballistics model to create probabilistic SDZs. This is due to the complicated nature of the model and the requirement for very precise input measurements and usage. While we would have liked to develop a RIP tool that is user-friendly enough for anyone to use, these restrictions on the use of the ballistics model also apply to the RIP Tool.

However, TRADOC is currently considering including the Picatinny ballistics model in the Range Manager's Toolkit (RMTK). Should they decide to include it, and should funding for a fully functional RIP Tool be awarded, we will provide the completed RIP Tool for inclusion in the RMTK as well.

Conclusions

The practical uses of the RIP Tool are numerous. One of the most pressing current needs is for more accurate and reliable data in estimating fire risk to protected resources. The sponsor of this project requires accurate data on where fires could start in order to reduce the perceived fire risk to threatened and endangered (T&E) species and their habitat. For lack of a better criterion, the current assessment developed by oversight agencies includes assuming that a fire could start anywhere within an SDZ. Because SDZs are so large, this assumption vastly inflates the area potentially at risk of ignition, and with larger caliber weapons, rockets, or artillery suggests that fires could start outside of the impact area and within T&E plant and animal populations.

The results from a RIP Tool analysis will provide a more realistic interpretation of where fires may start. Figures 7 and 12 provide a clear demonstration of the difference between using the SDZ and the RIP Tool to estimate where ignitions may occur. Using the RIP Tool grid output can help fire managers assess overall fire risk. As discussed in the Results and Discussion section, the grid outputs from the RIP Tool can be used to create far more realistic ignition inputs into wildfire simulations, such as the commonly used Fire Area Simulator (FARSITE), that make up a fire risk analysis. Determining where ignitions should be placed on the landscape is one of the most difficult parts of assessing fire risk. The RIP Tool can provide a concrete answer to this question and help to create a robust fire risk assessment. These simulations and assessments are invaluable for wildfire management planning and determining where firebreaks and wildfire fuel treatments will be most effective. Implementation of the RIP Tool at Schofield Barracks, for example, could substantially decrease the size of the area considered at risk of fire. It is expected that this will reduce the expenditures on T&E mitigation, currently in the millions of dollars per year, though by how much is unknown.

The grid outputs from the RIP tool can also provide a better visual reference than the more abstract and absolute idea of an SDZ for use in consultations with regulatory agencies, environmental documentation, or public meetings. This is useful to environmental specialists, lawyers, and public relations officers. The SDZs cover large areas and oversight agencies and/or the public may overestimate the likelihood of wildfire far from the target area, judging ignitions to be equally likely anywhere within the SDZ as discussed above. Because the grid output represents the spectrum of

ignition probabilities throughout the range, the task of explaining to outside oversight agencies that ignitions are much more likely near the targets and in the center of the range, and less likely behind hills or beyond the tracer burnout distance, is more straightforward. Being able to easily convey this information through visual representations can be vital during consultations or for environmental documentation such as environmental impact statements.

Another use of the RIP Tool is for range planning. By running the Tool on a proposed new range or a range realignment, range planners can easily visualize where ignitions are likely and adjust their planning accordingly. By including fire mitigation in the range planning process, the potential for unintended ignitions and wildfires can be mitigated before they ever become a problem. Small adjustments in range alignment or location can make significant differences in the likelihood of ignitions starting outside of an existing firebreak, for instance. Utilizing these techniques, the installation can maintain better control of ignition locations. As a result, installations can expect a lower incidence of fires in unexpected or sensitive locations and higher success rates in containing fires, most importantly higher intensity fires.

It is our hope that running the RIP Tool becomes a standard part of designing and realigning ranges in fire prone locations. We believe that an assessment of the safety of any range should include an fire risk assessment that considers potential impacts to protected resources, infrastructure, and human safety. With a fully functional RIP Tool available as part of the Range Manager's Toolkit, such an assessment would be possible at any range.

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